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Summary of the ATLAS ITk Strip Tracker Module Pre-production

Jia Jian Teoh[a,*]

On behalf of the ATLAS ITk Strip Community

[a] *Physics Department, University of Toronto,*
60 Saint George Street, Toronto, Ontario, Canada, M5S 1A7

E-mail: jia.jian.teoh@cern.ch

During the High-Luminosity Large Hadron Collider upgrade, the current ATLAS Inner Detector will be replaced with the new Inner Tracker in order to cope with the increased track density, harsher radiation environment and higher data rates. The ITk is designed to be an all-silicon tracking detector with a strip detector surrounding the inner pixel detector. The strip tracker will consist of a central barrel detector with four layers (12,000 modules total), and two end-caps, consisting of six discs each (7,000 modules total). The 19,000 modules required for the full detector will be assembled over the course of a production phase planned to last 50-54 months. Before that, 5% of the module production volume was assembled in order to exercise the full assembly and quality control chain. This contribution presents an overview of the pre-production phase results and discusses issues encountered, which are critical for ensuring the success of the upcoming production phase.

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*Speaker

1. Introduction

The Large Hadron Collider (LHC) is entering its High-Luminosity phase (HL-LHC), necessitating upgrades to its current detector systems. Among the most significant of these upgrades is the replacement of the existing ATLAS Inner Detector with a new, all-silicon Inner Tracker (ITk) [1]. This detector is crucial for accurately tracking particle collisions, which is fundamental to the experiment research objectives. The scale of this upgrade is immense, requiring the construction and integration of approximately 19,000 barrel and endcap type modules. Each module consists of a silicon strip sensor coupled with multiple flexes containing readout electronics. The precision assembly and rigorous quality control (QC) are paramount to the project's success. To ensure these standards, a pre-production phase was executed, during which 5% of the total production volume was assembled. This phase was critical in testing the entire assembly and QC process before full-scale production commenced.

2. Objective

The primary objective of the pre-production phase was to validate the assembly and QC procedures across different production sites. This phase aimed to:

- Ensure that all components met the stringent performance requirements for the ITk.
- Streamline the production process by standardizing tools and QC procedures.
- Identify and address any potential issues that could arise during full-scale production.

The results of this phase were intended to provide valuable feedback for refining assembly techniques and ensuring that all participating institutes were fully qualified and ready for large-scale production.

3. Methodology

3.1 Site Qualification

With nearly 30 module assembly institutes worldwide involved in the project, each site must undergo a rigorous qualification process before being allowed to commence full-scale module production. The qualification process involved full site qualification checks and the completion of the pre-production phase. All sites need to adhere to QC procedures which were standardized across all production sites to ensure consistency and reliability.

3.2 QC Procedures

The QC program for the ITk strip module production was designed based on past experiences with large-scale assemblies and R&D programs. It is divided into several key stages:

1. External parts QC: ensuring that all third-party manufactured parts were suitable for use.
2. In-situ/post-assembly QC: verifying the correctness of assembly at each stage and ensuring readiness for subsequent steps.

3. Performance QC: assessing the performance of parts to ensure they met the specifications required for the ATLAS detector.

4. Reception QC: checking that parts were not damaged during shipping and handling.

For module assembly, module QC mainly involves metrology and electrical and thermal testing. Precise metrology measurements were conducted to ensure that all components were correctly assembled. This included measuring the positions of hybrids and powerboards, as well as glue heights. Various tools, such as optical systems and laser ranging measurement systems, were used for these measurements. The results were cross-validated across different sites to ensure consistency.

Modules underwent a series of electrical tests to evaluate their performance under various conditions. These tests involve assessing the threshold, gain, input noise, output noise, and noise occupancy of each strip/channel. Moreover, IV measurement are also performed to check for early breakdown or any physical damage of the sensor. Thermal cycling tests are carried out to evaluate the module's thermo-mechanical properties and performance under extreme temperature conditions.

4. Results

The pre-production phase yielded important insights and results. Overall the pre-production phase was largely successful, with most sites achieving over 90% qualification steps. Database structures were established, and tools and interfaces were developed for tracking and managing the production process. An acceptable module production yield ranging from 70% to 100% (depending on the module type) was achieved. The QC procedures identified several issues, such as tooling mismatches and powerboard noise, which were addressed to improve the assembly process. Despite the overall success, some challenges remained, particularly related to cold noise, sensor cracking and early module HV breakdowns. These issues were investigated, and potential solutions were proposed.

5. Conclusions and Future Work

The ATLAS ITk Strip Module pre-production phase was a critical step in preparing for the full-scale production of the ITk detector. The insights gained from this phase will help streamline the production process and ensure that all modules meet the necessary performance standards. The remaining challenges highlight the need for continued investigation and collaboration among the various production sites to ensure the success of the ATLAS ITk Strip upgrade.

Moving forward, the focus will be on refining the assembly processes, further qualifying production sites, and addressing the remaining technical challenges. The successful completion of these tasks will pave the way for the full deployment of the ITk detector, which is essential for the future research capabilities of the HL-LHC.

References

[1] ATLAS Collaboration. Technical Design Report for the ATLAS Inner Tracker Strip Detector. Technical report, CERN, Geneva, 2017.